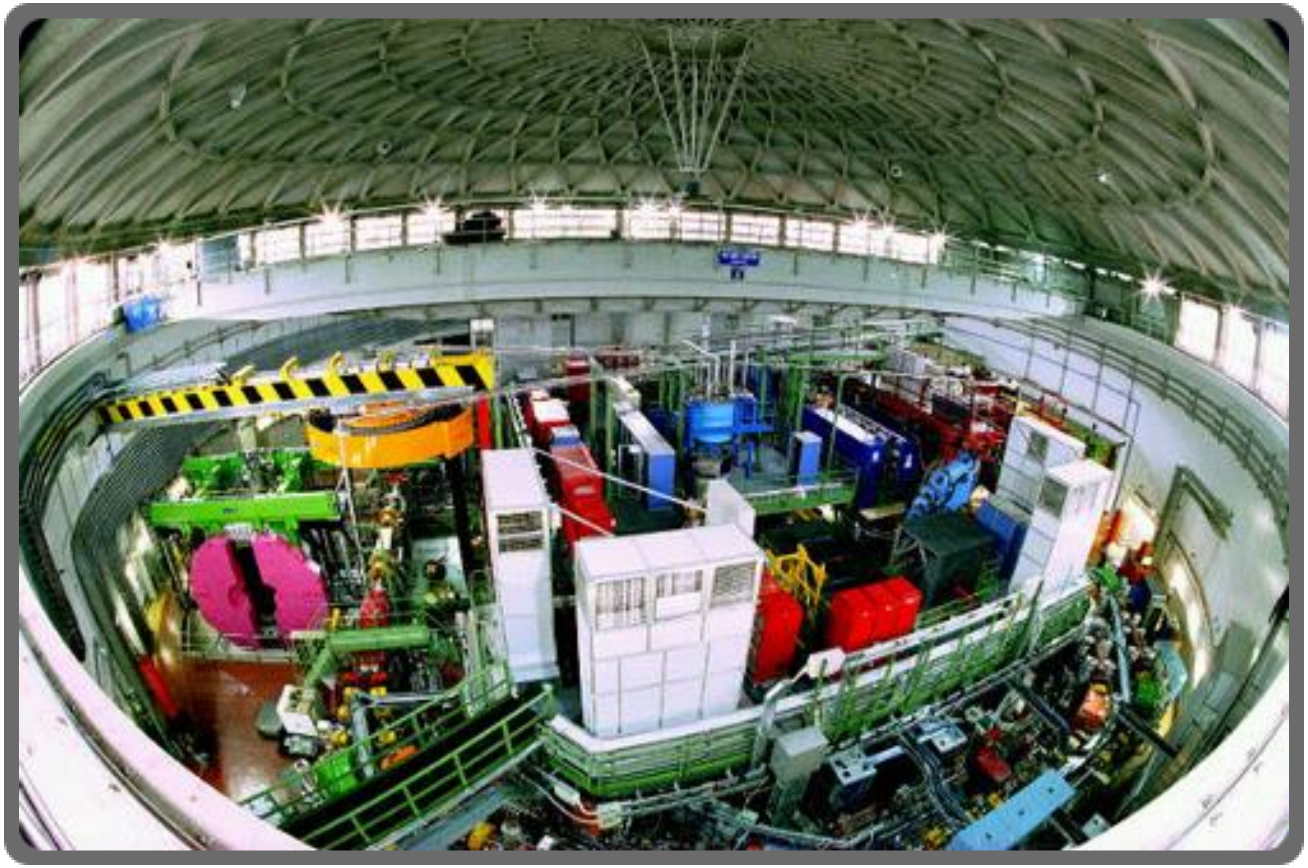
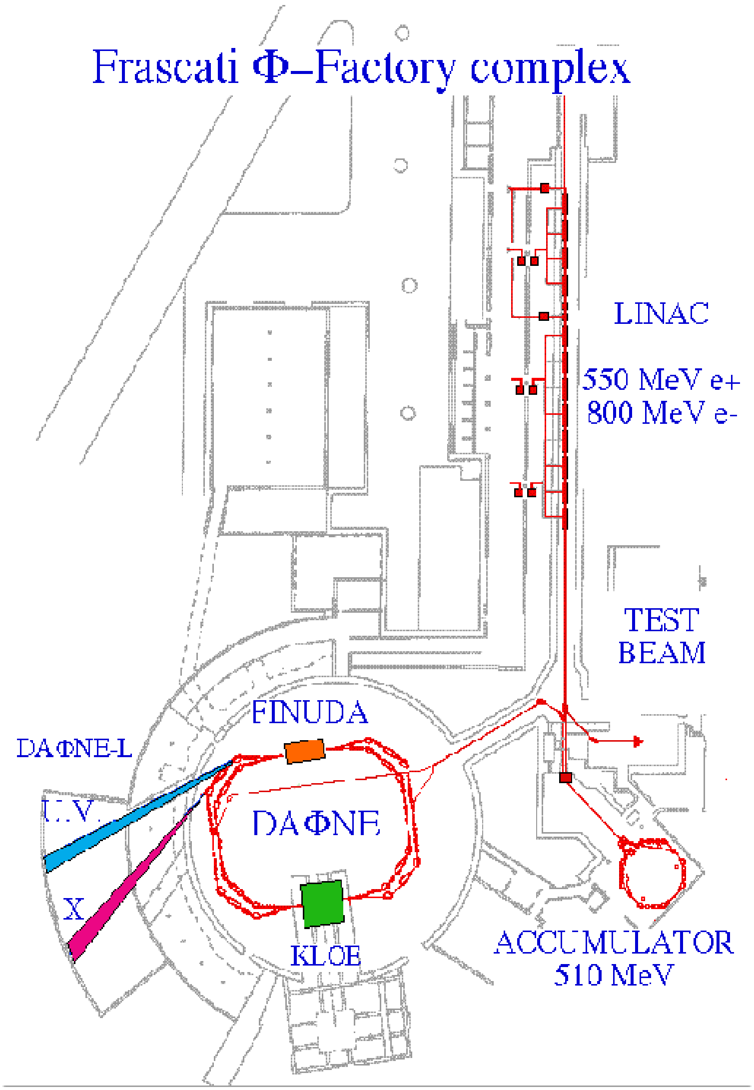
Physics at DAΦNE and KLOE-2



M. Martemyanov, ITEP, Moscow

DAΦNE accelerator complex



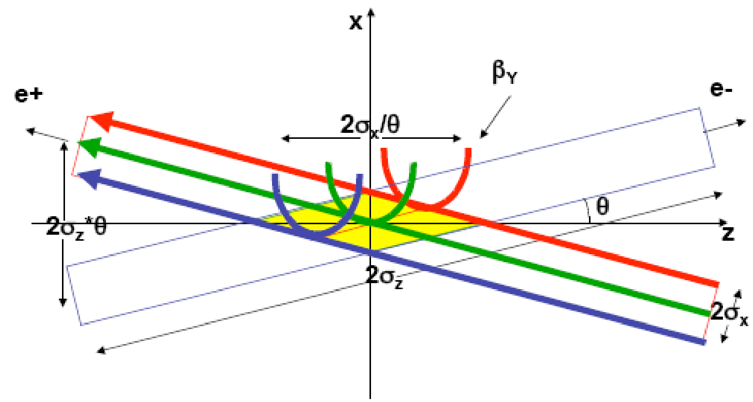
- e^+e^-– collider at ϕ–meson peak (1020 MeV)
- 2 interaction regions
- Trajectory length : 97.69 m
- Number of stored bunches: up to 120
- ϕ – momentum : ~ 13 MeV/c

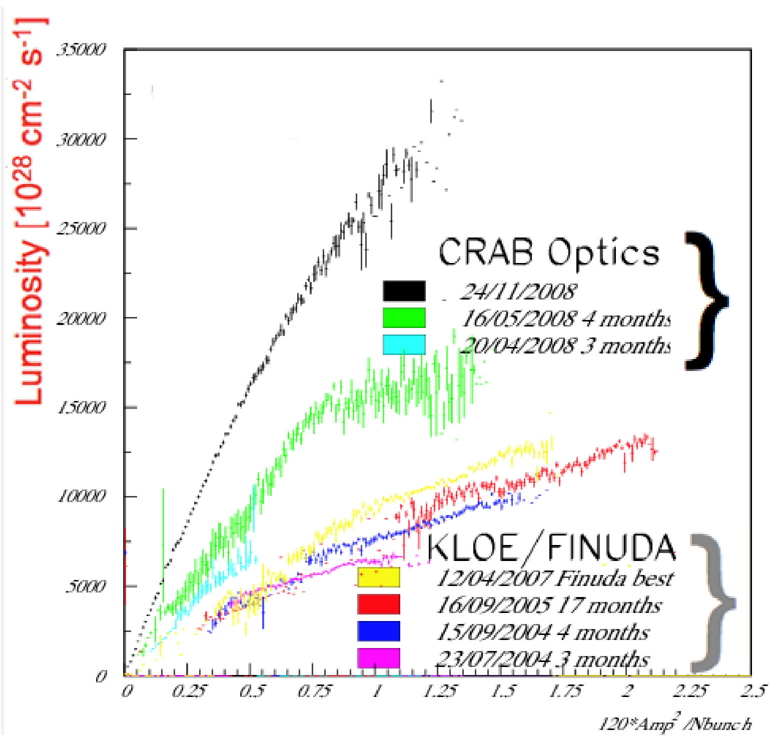
First data taking period : **1999 – 2006**
Best result :

$$\boldsymbol{L = 1.4 \times 10^{32}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}}$$
$$\boldsymbol{\int L dt = 8.5\ \mathrm{pb}^{-1}/\ \mathrm{per\ day}}$$

In 2008 DAΦNE has implemented a new interaction scheme based of a large Piwinski angle (ψ) and crab-waist compensation induced by properly designed sextupoles

$$\psi \approx \frac{\sigma_Z}{\sigma_X} \times \frac{\theta}{2} \qquad \beta_y \approx \frac{\sigma_X}{\theta} << \sigma_Z$$





New collision scheme (tested with the SIDDHARTA experiment)
Large angle and crabe-waist compensation ψ = 1.9, βy* = 9 mm

Peak luminosity
Lnew ~ 3×Lold

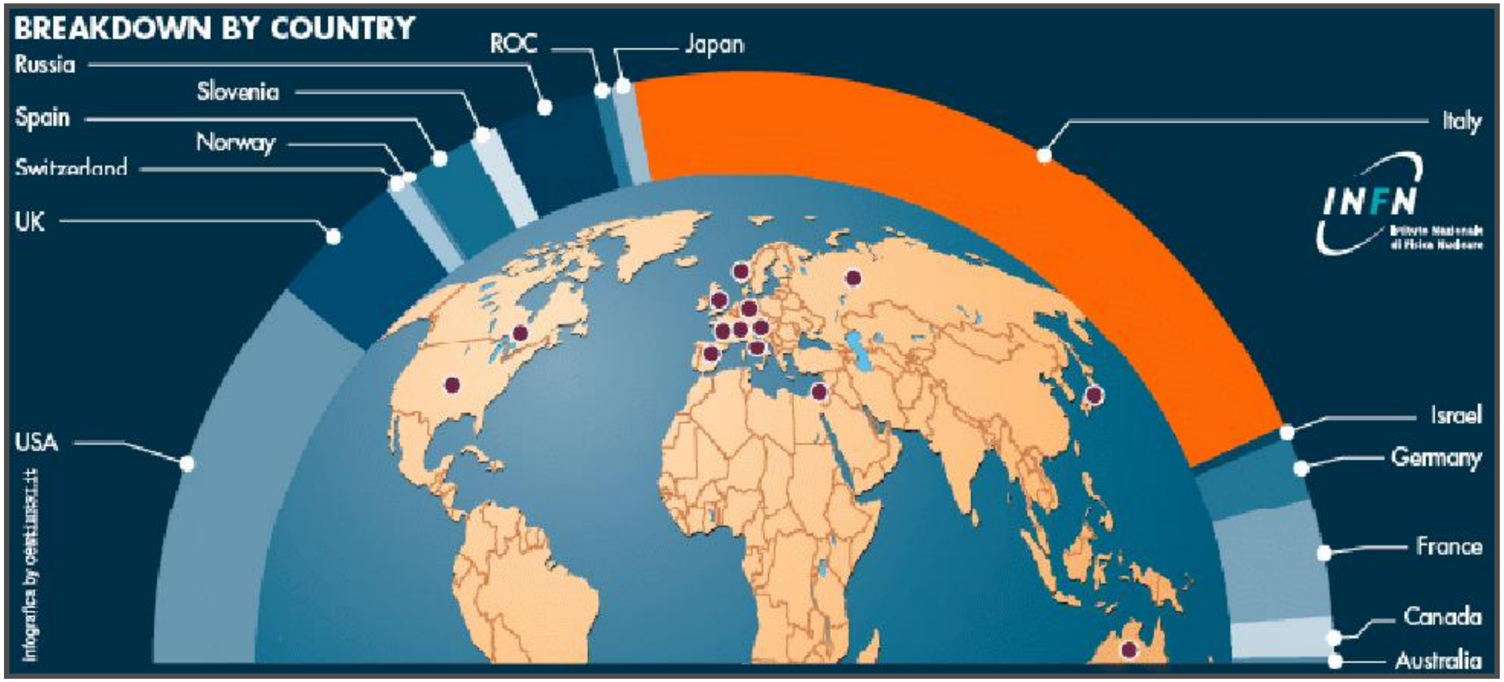
Old collision scheme
KLOE 2005 ψ = 0.6, βy* = 18 mm
KLOE 2002 ψ = 0.3, βy* = 25 mm

DAΦNE / future plans

- New director (U. Doselli since June 2011) stated that LNF is committed to running DAΦNE and to delivering the luminosity to make KLOE–2 a successful experiment

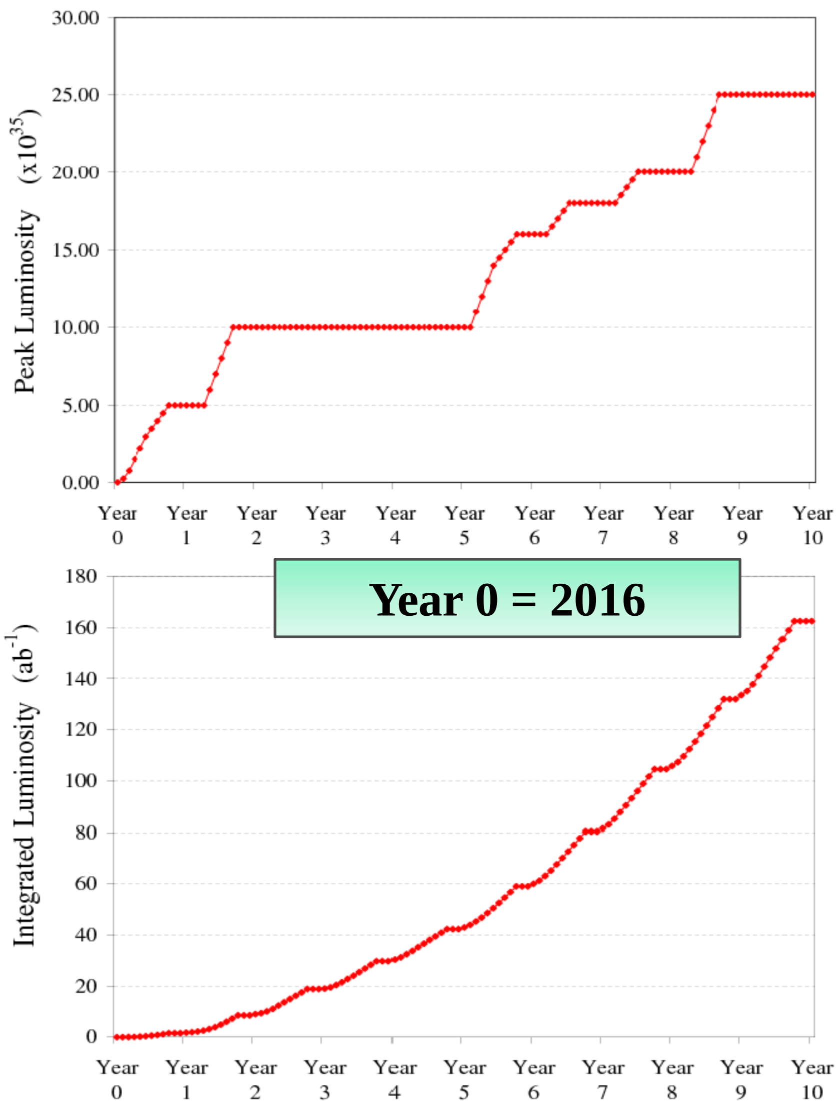
- Recent time (2009 – 2011 years) AD had too much problem to start upgraded collider
- Now the planned time to begin KLOE–2 operations is Novermber 2001
- Time reserved for KLOE–2 data –taking is around 2 or 3 years
- As SuperB construction begins, DAΦNE running should be winding down.
- SuperB will be funded separately from INFN base budget
- Now (April 2011) the site of new project was chosen : campus of the Tor Vergata University (Roma 2)

SuperB / recent news



- In SuperB is inserted in April 2010 among the Italian National Research Program (PNR) as a flagship project
- In April 2011 PNR approved 250M for next four years
- Special Russian–Italian agreement for SuperB and funding – managed through "Kurchatov Institute" (70M)

SuperB project

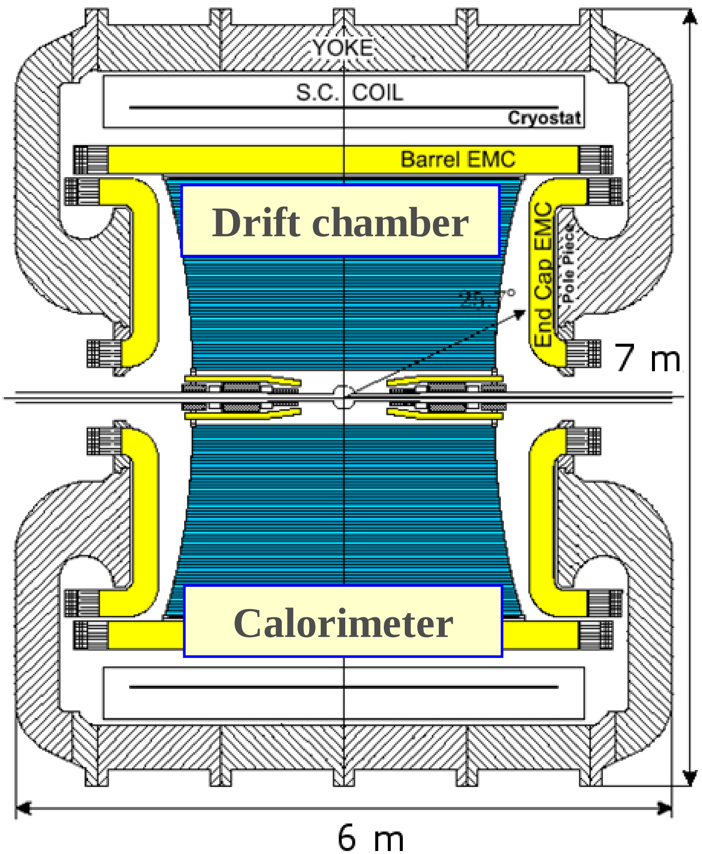


- e^+e^- – asymmetrical collider
- Max. energy up to 4 and 7 GeV
- Flexible running energy
- Starting luminosity at large Piwinski angle

$$L = 1 \times 10^{36}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$$

- Luminosity upgrade to $2.5\times10^{36}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ after 5 years of running
- Two distinct modes of operation:
  - ✓ 4S region $\Upsilon(1S) - \Upsilon(6S)$
  - ✓ Charm threshold region: $\psi(3770)$ and nearby thresholds
- Super Flavour Factory at large data sample
- Alternative way to search for new physics beyond the LHC scale

KLOE – detector



Magnet, B = 0.52 T

Drift chamber

- Large volume : ∅ = 4m, L = 3.3 m
- Gas mixture : 90 % He + 10% C_4H_{10}
- Resolutions : σxy = 0.15 mm, σz = 2 mm

  $\delta p/p$ = 0.4 %, $\sigma_{vertex} \sim 1$ mm

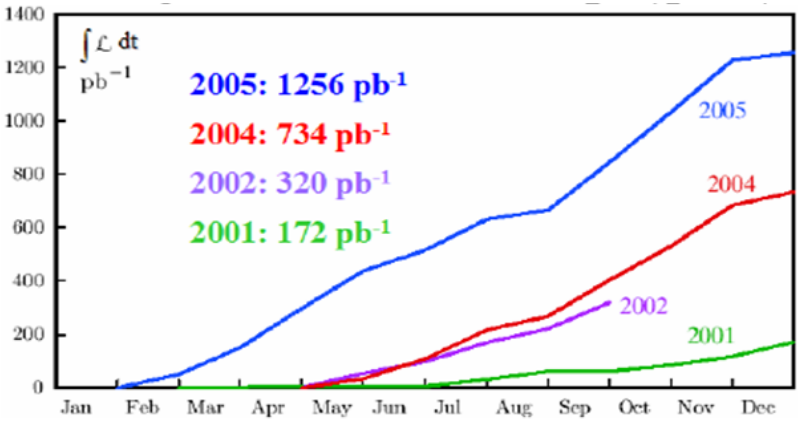
Calorimeter

- Construction : lead / scintillating fibers
- Solid angle coverage: 98%
- Resolutions : $\sigma E/E = 5.7\ \%/\sqrt{E(GeV)}$

  $\sigma t = 55\ ps/\sqrt{E(GeV)} \oplus 100ps$
- PID capabilites

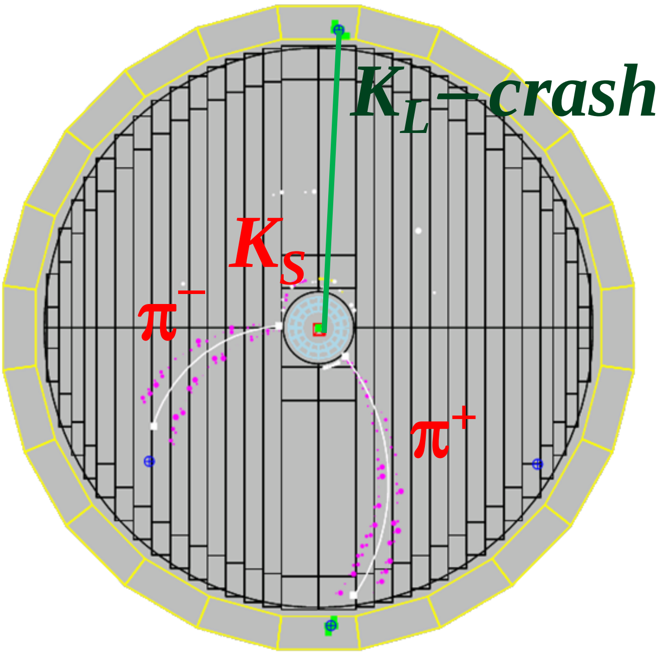
Physics at KLOE/KLOE–2

From 2001 to 2005 KLOE collected ~ 2.5 fb^{-1} (8×10^9 ϕ – meson decays)



Decay channel	Events (2.5 fb^{-1})
K^+K^-	3.7×10^9
K_SK_L	2.5×10^9
$\rho\pi + \pi^+\pi^-\pi^0$	1.1×10^9
$\eta\gamma$	9.7×10^7
$\pi^0\gamma$	9.4×10^6
$\eta'\gamma$	4.6×10^5
$\pi\pi\gamma$	2.2×10^6
$\eta\pi^0\gamma$	5.2×10^5

Tagging Kaon beams

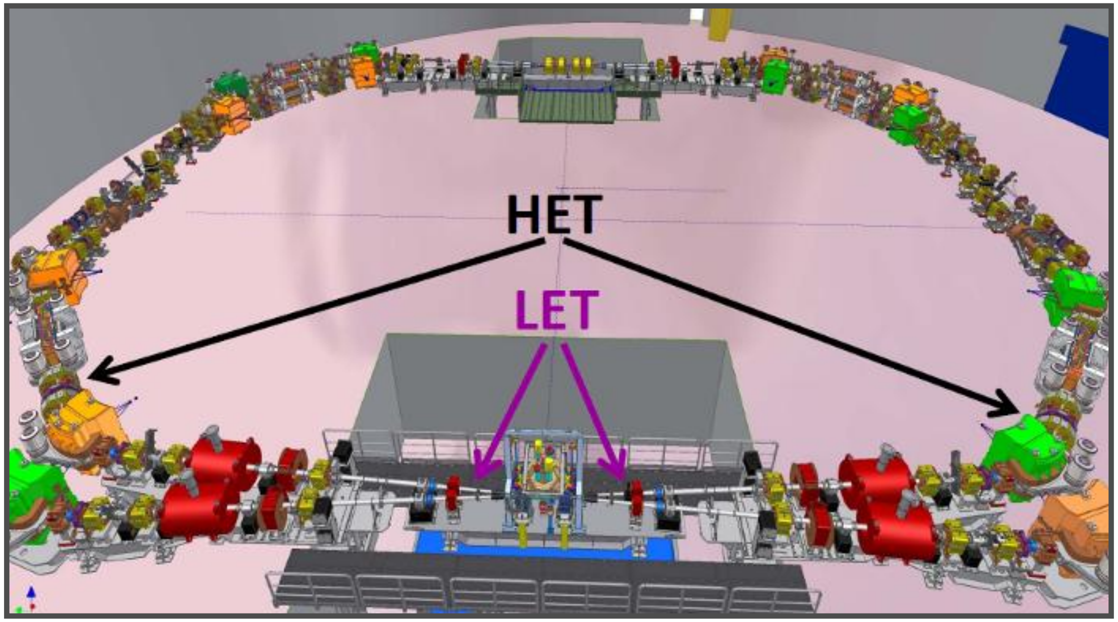


KLOE–2 Step 0

Minimal detector upgrade for the first KLOE–2 run (~ 5 fb^{-1} for one year data taking): taggers to detect electron and positrons from

$$e^+e^- \to e^+e^- \gamma^* \gamma^* \to e^+e^- X$$

Two type of taggers are installed :



LNF Note 10/17(P), 2010

Low Energy Tagger (LET)

- 1.5 m from IP
- 160 < E < 230 MeV

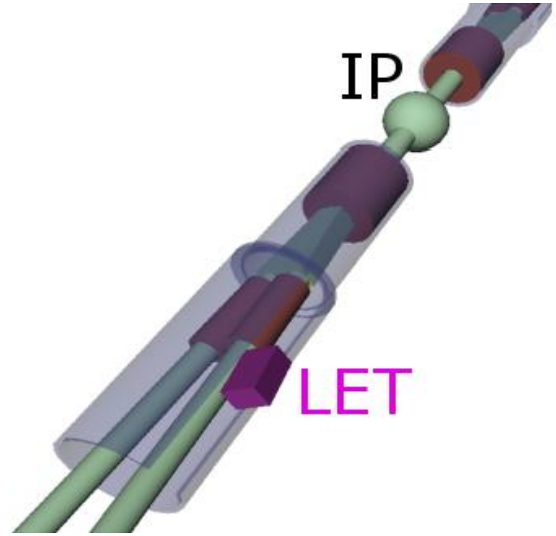
High Energy Tagger (HET)

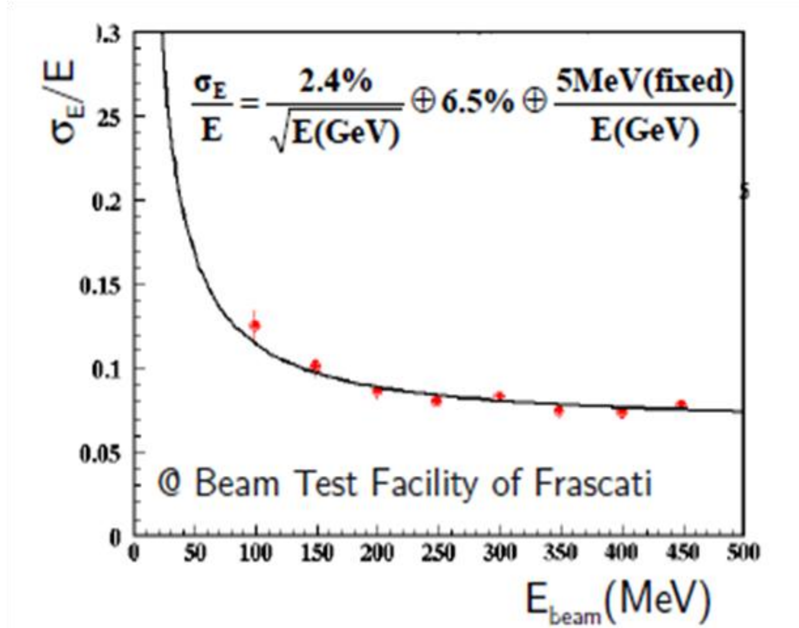
- 11 m from IP
- E > 400 MeV

LET tagger

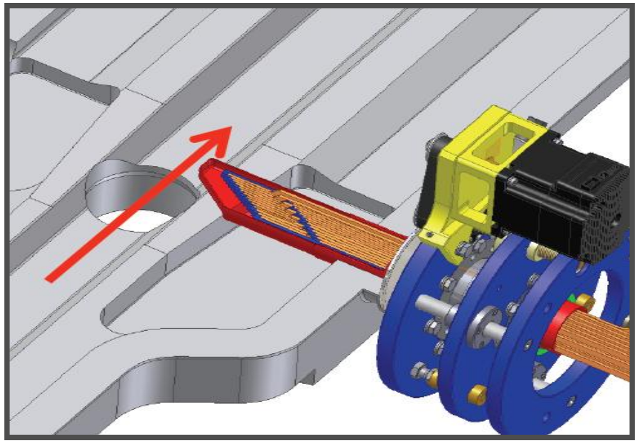
- LET – calorimeter detector
- It installed inside KLOE–2
- Size : 6 cm × 7.5 cm ×12 cm
- LET constructed from 20 LYSO crystals (X_0 ~1 cm) and coupled to the SiPM
- Good energy resolution was obtained on small prototype :

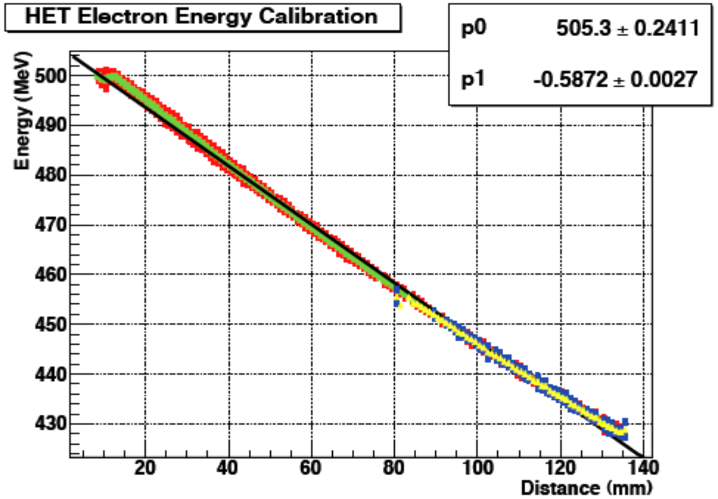
  $\sigma E/E < 10$ % at $E < 100$ MeV





HET tagger





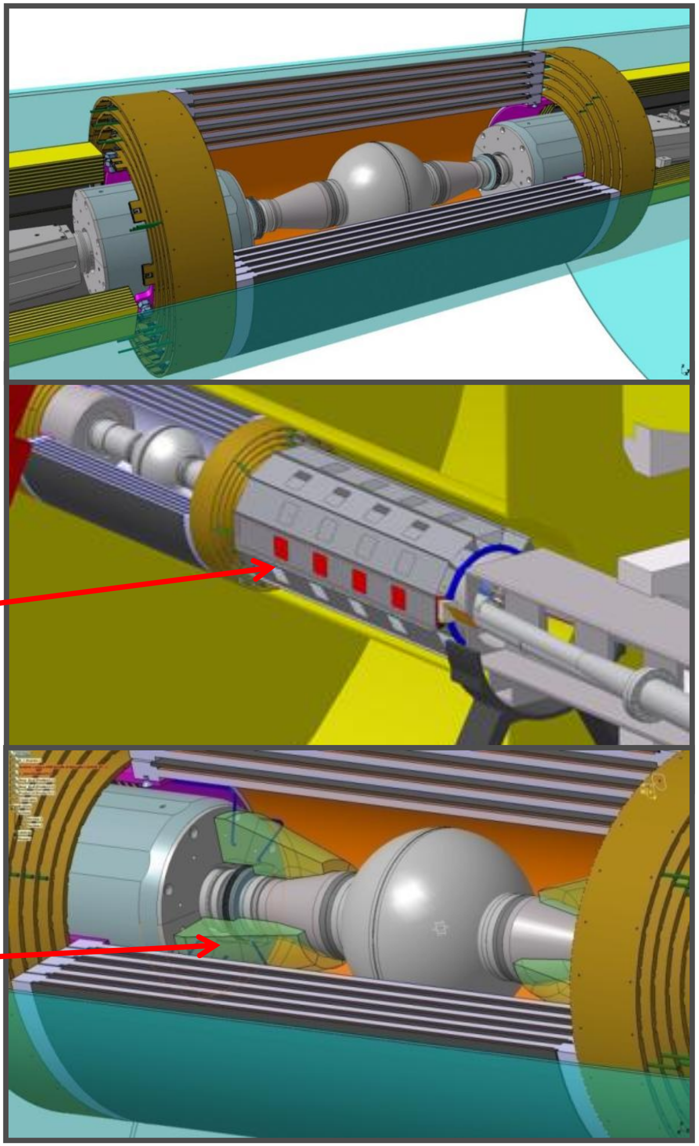
- HET – position detector (hodoscope) and provides a measurement of the scattered leptons with respect to nominal orbit
- There is a strong correlation between energies and displacement in the horizontal plane
- Detector position can be moved between 30 – 50 mm from beam
- Hodoscope made by two rows of 15 scintillators (3×5×6 mm^3)
- Spatial resolution: 5mm; time resolution: ~200 ps
- Active part of the detector has been assembled with their mechanical structure. Installation is planned to be within September 2011

KLOE – 2 Step 1

- **IT** (Inner Tracker) installation (between beam pipe and drift chamber) to improve tracking and vertex reconstruction of the charged particles decaying near IP

- **QCALT** (Quadrupole tile calorimeter) : detection of the γ's coming from K_L – decays in the drift chamber

- **CCALT** (Crystal calorimeter): increase acceptance for γ's from IP (polar angle from 21^0 down to 10^0)



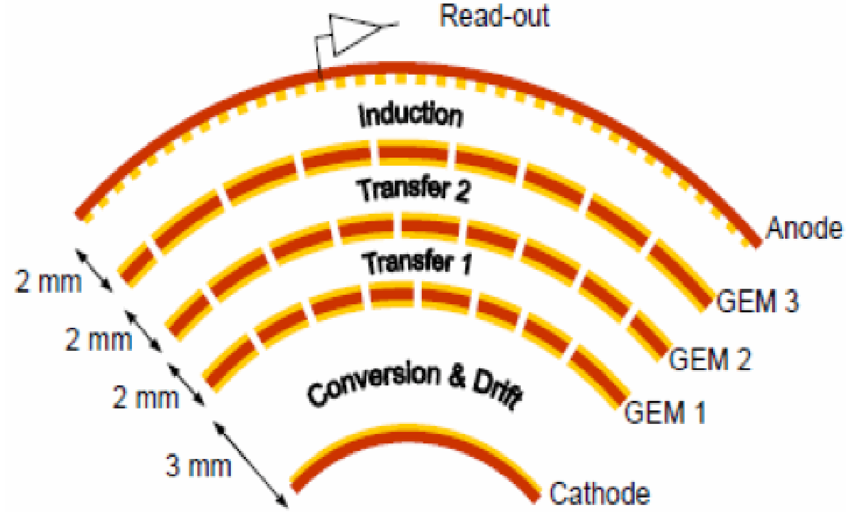
Inner Tracker

- Main physics goals : vertex reconstruction in the K_S, η, η' – decays and in $K_S - K_L$ interference measurement
- Cylindrical GEM (CGEM) detector was proposed and built for the first time ever
- XV strips – pads readout
- 4 CGEM layers with radii from 13 to 23 cm from IP and before DC wall
- Spatial resolution :

$$\sigma_{r\phi} \sim 200\ \mu\text{m}, \quad \sigma_z \sim 500\ \mu\text{m}$$

- 700 mm active length
- Radiation length in the active volume is 1.5% X_0

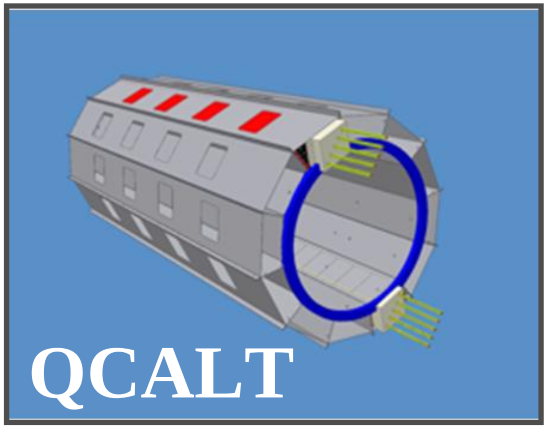
LNF Note 10/3(P), 2010

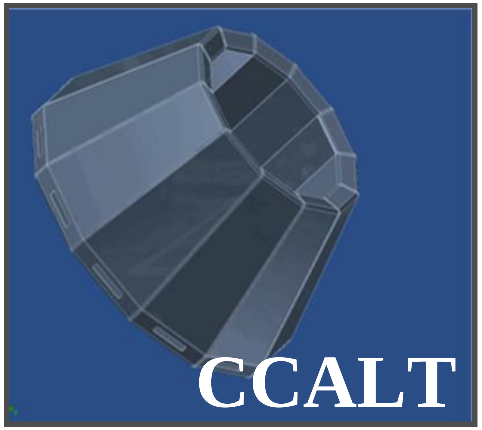


- CGEM design requirements, performance and XV readout scheme validated with exhaustive R&D phase

The construction of the Inner Tracker was started and planned to be completed next summer

QCALT and CCALT – calorimeters





- ✓ QCALT located along beam–line
- ✓ Two dodecagonal structures (1 m length)
- ✓ 5 layers with tungsten (thick = 3.5 mm) + tiles (5mm) + air gap (1mm) for a total 5.5 X0
- ✓ 20 cells / row for a total of 2400 readout channels
- ✓ Fast timing resolution < 1ns
- ✓ Readout was performed with 400 pixels SiPM (MPPC)

- ➢ CCALT composed of two small barrels of 24 LYSO crystals each
- ➢ Each crystal has a length of 10 –13 cm and transverse area from 1.5×1.5 cm^2 to 2×2 cm^2
- ➢ Time resolution : 300–500 ps for 20 MeV photons
- ➢ Readout was done with SiPM

KLOE – 2 physics program

Main purpose : collect 20 fb^{-1} at the DAΦNE upgraded luminosity using the crab–waist scheme

✓ Kaon physics

- Test of CPT in correlated kaon decays and Ks – semileptonic decays
- Test of SM (CKM unitarity and lepton universality)
- Test of ChPT in Ks – decays

✓ Spectroscopy of the light mesons

- η, η', a_0, f_0, σ from ϕ – radiative decays

✓ $\gamma\gamma$ - physics

- Scalar resonances in two photon collisions ($e^+e^- \rightarrow e^+e^- \pi^+\pi^-$)
- Single pseudoscalar final state

✓ Dark matter searches

- Light U – boson (low energy region)

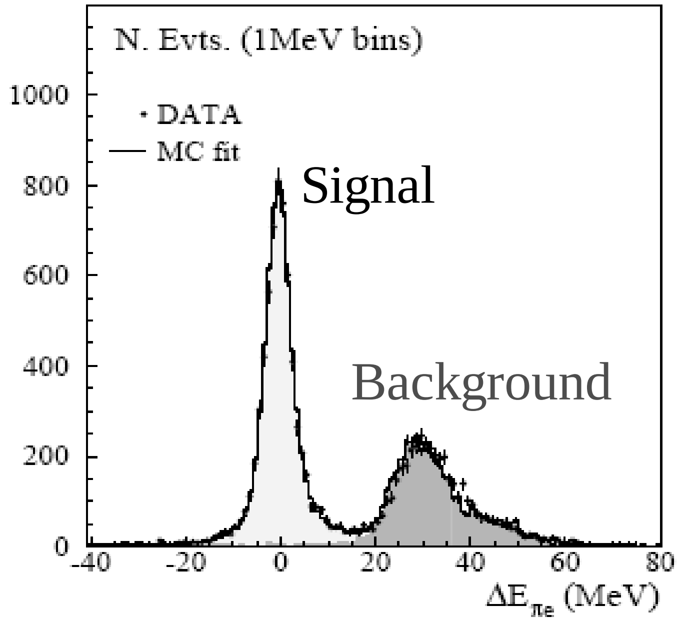
KLOE–2 physics program : G. Amelino-Camelia *et al.*, Eur.Phys.J. C68, 619 (2010)

CPT–symmetry test in Ke3 decays

$$A_{S,L}=\frac{\Gamma(K_{S,L}\to\pi^-e^+\nu)-\Gamma(K_{S,L}\to\pi^+e^-\bar{\nu})}{\Gamma(K_{S,L}\to\pi^-e^+\nu)+\Gamma(K_{S,L}\to\pi^+e^-\bar{\nu})}$$

CPT invariance : $A_S = A_L = 2Re\varepsilon \sim 3\times10^{-3}$

KLOE result: $A_S = (1.5 \pm 9.6_{stat} \pm 2.9_{syst})\times10^{-3}$



KTEV(02): $A_L = (3.32 \pm 0.06_{stat} \pm 0.05_{syst})\times10^{-3}$

✓Result based on *Lint* = 410 pb^{-1} sample and statistical error gives a main contribution

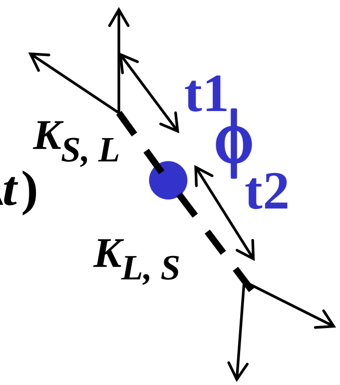
✓With IT installation and KLOE (KLOE–2) statistics it's expected 0.3 % on *BR(Ks→πe ν)*

F. Ambrosino *et al*., Phys. Lett. B636, 173(2006)

Quantum decoherence

Interference between two kaons in the entangled state has been observed in $\phi \to K_S K_L \to \pi^+ \pi^- \pi^+ \pi^-$ by the KLOE (2005).

$\Delta t = t1 - t2$



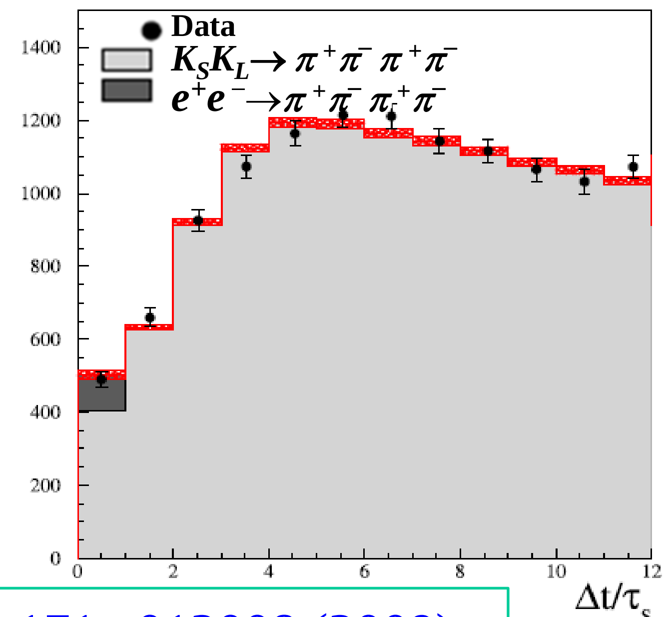
$$I(\pi^+\pi^-, \pi^+\pi^-; \Delta t) \propto e^{-\Gamma_L \Delta t} + e^{-\Gamma_S \Delta t} - 2(1-\zeta_{SL}) e^{-(\Gamma_S+\Gamma_L)/2\Delta t} \cos(\Delta m \Delta t)$$

ζ_{SL} – decoherence parameter (in the $\{K^0 \bar{K}^0\}$ basic defined as $\zeta_{0\bar{0}}$)

KLOE result based on 1.5 fb^{-1}

$\zeta_{SL} = (0.3 \pm 1.8_{stat} \pm 0.6_{syst}) \times 10^{-2}$

$\zeta_{0\bar{0}} = (1.4 \pm 9.5_{stat} \pm 3.8_{syst}) \times 10^{-7}$



Compatible with the prediction: $\zeta_{SL} = \zeta_{0\bar{0}} = 0$ (no decoherence effect and good test of CPT coservation)

A. Di Domenico *et al*., J.Phys.Conf.Ser. 171, 012008 (2009)

CP–violation in $K_S \to 3\pi^0$

✓ $K_S \to 3\pi^0$ is a pure *CP* – violating process

✓ *CP* – violation is parameterized as : $\eta_{000} = \dfrac{A(K_S \to \pi^0\pi^0\pi^0)}{A(K_L \to \pi^0\pi^0\pi^0)} = \varepsilon + \varepsilon'_{000}$

where ε and ε'_{000} quantify indirect and direct *CP* – violation . Assuming that

$\eta_{000} \sim \varepsilon$ one can estimate BR($K_S \to 3\pi^0$) $\sim 1.9 \times 10^{-9}$

✓ Search of the decay was performed by KLOE with a pure K_S beam obtained

by K_L interaction in the calorimeter (K_L – crash) and detecting six photons for

Lint = 450 pb^{-1}

$$\mathrm{BR}(K_S \to 3\pi^0) < 1.2 \times 10^{-7} \text{ and } |\eta_{000}| < 0.018$$

F. Ambrosino *et al*., Phys.Lett. B619, 61(2005)

- New procedure to refine cluster reconstruction has been obtained
- KLOE–2 expectation: an upper limit lower than 10^{-8}

KLOE–2 sensitivity to CP/CPT

Mode	Parameter	Present best measurement	KLOE–2 (25 fb^{-1})
$K_S \rightarrow \pi e \nu$	A_S	$(1.5 \pm 11) \times 10^{-3}$	$\pm 1 \times 10^{-3}$
$\pi^+\pi^- \quad \pi l \nu$	A_L	$(332.2 \pm 5.8 \pm 4.7) \times 10^{-5}$	$\pm 4 \times 10^{-5}$
$\pi^+\pi^- \quad \pi^0\pi^0$	$Re(\varepsilon'/\varepsilon)$	$(1.65 \pm 0.26) \times 10^{-3}$	$\pm 0.3 \times 10^{-3}$
$\pi^+\pi^- \quad \pi^0\pi^0$	$Im(\varepsilon'/\varepsilon)$	$(-1.2 \pm 2.3) \times 10^{-3}$	$\pm 4 \times 10^{-3}$
$\pi^+\pi^- \quad \pi^+\pi^-$	Δm	$(5.288 \pm 0.043) \times 10^9\ s^{-1}$	$\pm 0.05 \times 10^9\ s^{-1}$
$\pi^+\pi^- \quad \pi^+\pi^-$	ζ_{SL}	$(0.3 \pm 1.9) \times 10^{-2}$	$\pm 0.2 \times 10^{-2}$
$\pi^+\pi^- \quad \pi^+\pi^-$	$\zeta_{0\bar{0}}$	$(0.1 \pm 1.0) \times 10^{-6}$	$\pm 0.1 \times 10^{-6}$
$\pi^+\pi^- \quad \pi^+\pi^-$	α	$(-0.5 \pm 2.8) \times 10^{-17}$ GeV	$\pm 2 \times 10^{-17}$ GeV
$\pi^+\pi^- \quad \pi^+\pi^-$	β	$(2.5 \pm 2.3) \times 10^{-19}$ GeV	$\pm 0.2 \times 10^{-19}$ GeV
$\pi^+\pi^- \quad \pi^+\pi^-$	γ	$(1.1 \pm 2.5) \times 10^{-21}$ GeV	$\pm 0.3 \times 10^{-21}$ GeV
$\pi^+\pi^- \quad \pi^+\pi^-$	$Re(\omega)$	$(-1.6\ ^{+3.0}_{-2.1} \pm 0.4) \times 10^{-4}$	$\pm 3 \times 10^{-5}$

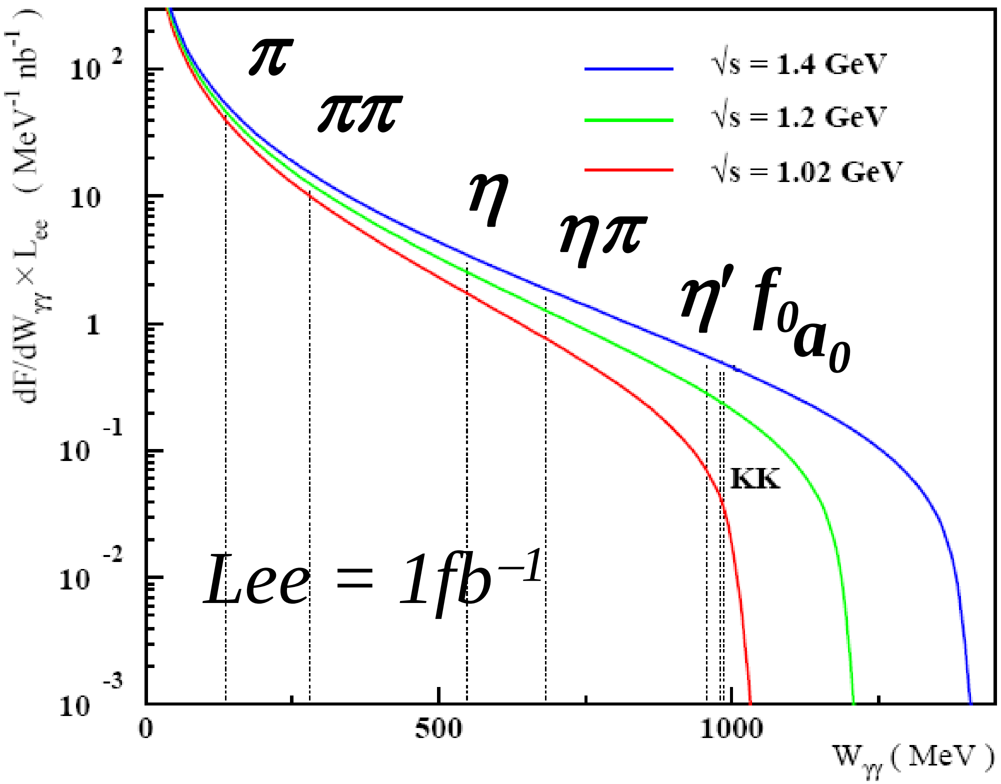
KLOE current resolution : **$\sigma(\Delta t) \sim \tau_S$**, IT installation gives **$\sigma(\Delta t) \sim 0.3\tau_S$**

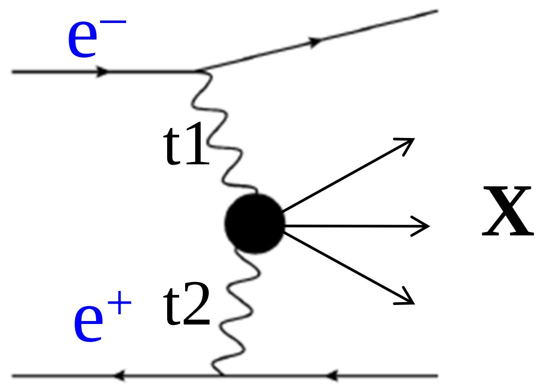
$\gamma\gamma$ – physics

$$e^+e^- \to e^+e^- \gamma^* \gamma^* \to e^+e^- X$$

$$N_{eeX} = L_{ee} \int \frac{dF}{dW_{\gamma\gamma}} \sigma_{\gamma\gamma \to X}(W_{\gamma\gamma}) dW_{\gamma\gamma}$$

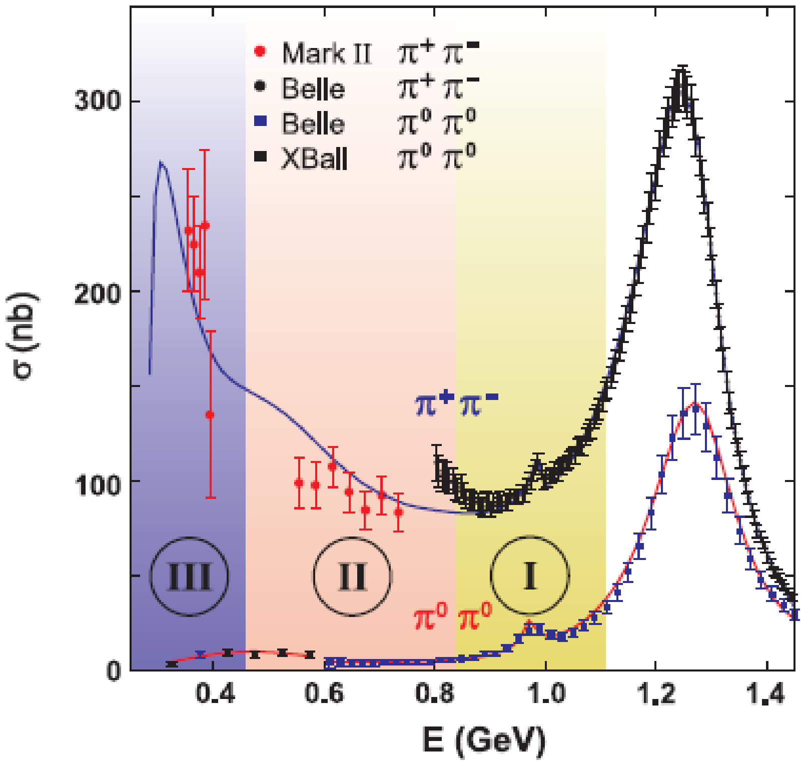
L_{ee} – integrated luminosity
$W\gamma\gamma$ – invariant mass of 2 γ's



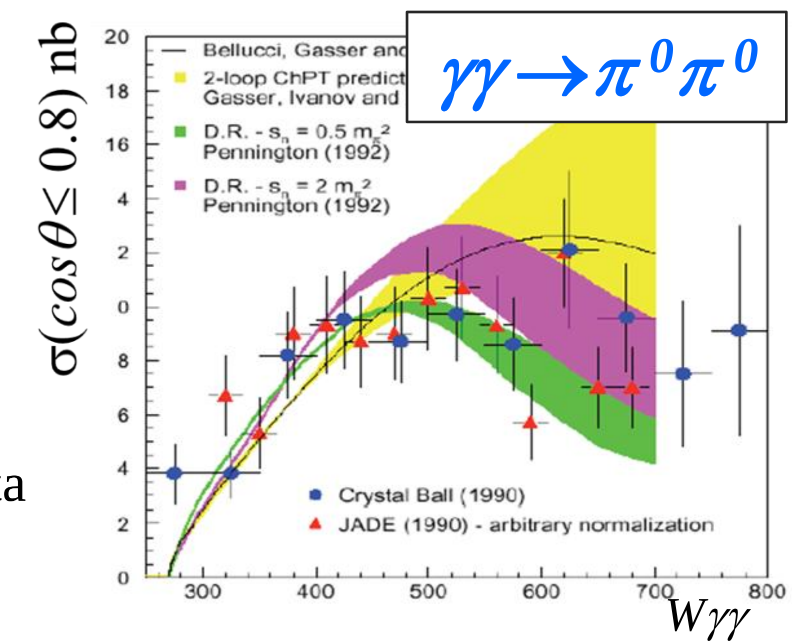


Taggers are essential to reduce background from ϕ–decays and close kinematics

$\gamma\gamma \rightarrow \sigma \rightarrow \pi\pi$



- IInd region (450–850 MeV) contains peak of scalar resonance σ, or $f_0(600)$
- Structure of σ (qq̄ or qqq̄q̄) is under discussion
- Values of mass and width are known with large uncertainties



✓ Best way to search : $\pi^0\pi^0$

✓ $\pi^+\pi^-$ channel has a large $\mu^+\mu^-$ bckg.

✓ Analysis was started on the KLOE data

Single pseudoscalar mesons

Final states : $X = P = \pi^0, \eta, \eta'$

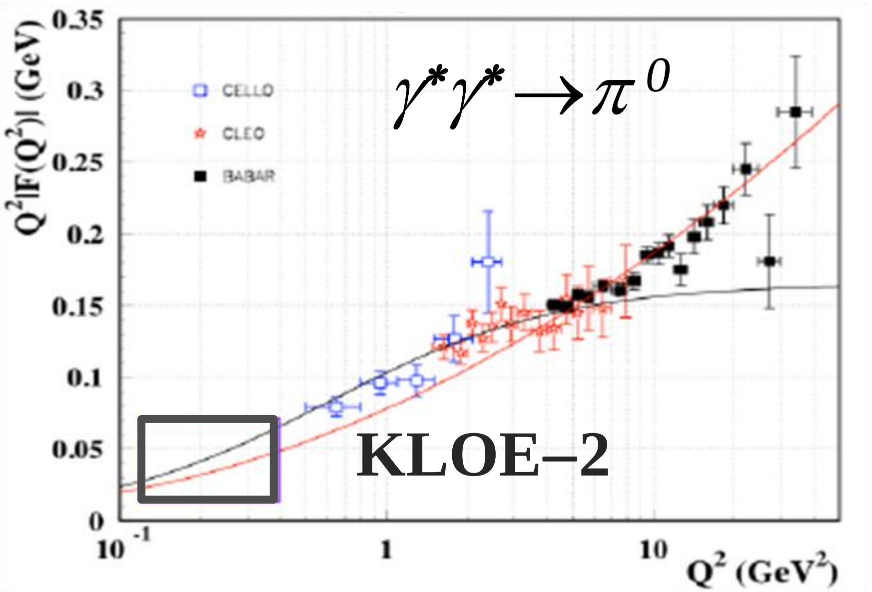
$\sqrt{s}$ (GeV)	1.02	1.2	1.4
$\sigma(e^+e^- \to e^+e^- \pi^0)$ nb	271	371	364
$\sigma(e^+e^- \to e^+e^- \eta)$ nb	45	66	90
$\sigma(e^+e^- \to e^+e^- \eta')$ nb	4.9	20	40

- Measurement of two–photons decay width $\Gamma(P \to \gamma\gamma)$ which can be extracted from cross sections $\sigma(e^+e^- \to e^+e^- P)$

$\Gamma(P \to \gamma\gamma)$ is used for calculation of the mixing angle (φ_P) and gluonium content ($Z_G^2 = \sin^2\phi_G$)

- Measurement of the form factors $\gamma^*\gamma^* \to \pi^0, \eta$ at low Q^2

$0.02\ \mathrm{GeV}^2 < Q^2 < 0.4\ \mathrm{GeV}^2$



$\eta - \eta'$ mixing and η' gluonium content

η' meson is considered a good candidate to host a gluon condensate. This question has been extensively investigated but it's still without a definite conclusion

$$|\eta'\rangle = \cos\phi_G \sin\varphi_p \frac{1}{\sqrt{2}} |u\bar{u} + d\bar{d}\rangle + \cos\phi_G \cos\varphi_p |s\bar{s}\rangle + \sin\phi_G |gluonium\rangle$$

$$|\eta\rangle = \cos\varphi_p \frac{1}{\sqrt{2}} |u\bar{u} + d\bar{d}\rangle - \sin\varphi_p |s\bar{s}\rangle$$

φ_P: $\eta - \eta'$ mixing angle

$Z_G^2 = \sin^2\phi_G$ gluonium content

KLOE measurement: $R\phi = \dfrac{BR(\phi \to \eta'\gamma)}{BR(\phi \to \eta\gamma)} = (4.77 \pm 0.09_{STAT.} \pm 0.19_{SYST.}) \times 10^{-3}$

related to the mixing angle and gluonium content.

$\varphi_P = (40.4 \pm 0.6)^0$ $Z_G^2 = 0.12 \pm 0.04$ at

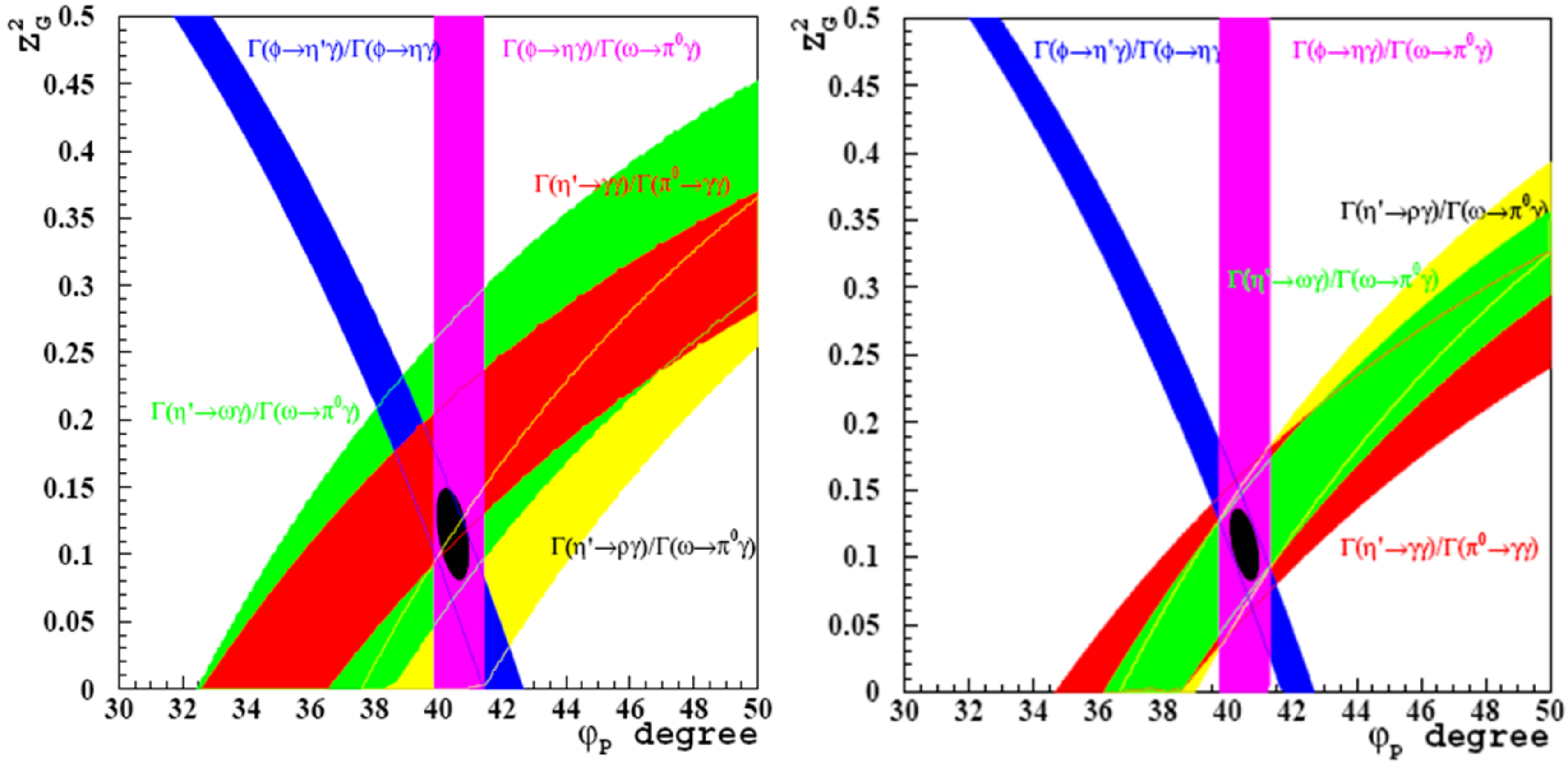
$\chi^2/\text{ndf} = 4.6/3$ $P(\chi^2) = 20\%$

F. Ambrosino *et al.*, JHEP 0907, 105(2009)

$\eta - \eta'$ mixing: from KLOE to KLOE–2

KLOE : global fit with 6 free parameters to various relation between hadronic widths

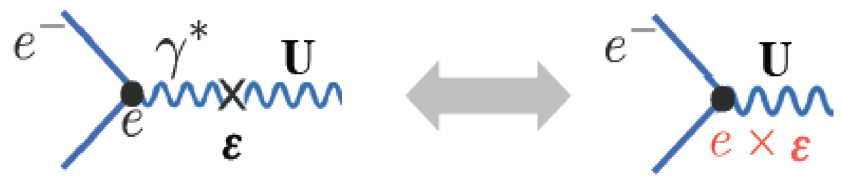
KLOE–2 expxectation measuring of η' branching ratio with 1 % accuracy



Recent observations from independent experiments (**PAMELA, ATIC, INTEGRAL, DAMA/LIBRA**) can be explained by a secluded gauge sector (U – boson with mass near the GeV scale). U – boson couples the secluded sector to SM through its kinetic mixing (mixing parameter $\varepsilon \lesssim 10^{-3}$)

R. Essig *et al.*, Phys.Rev. D80:015003 (2009)

Possible scenarios :



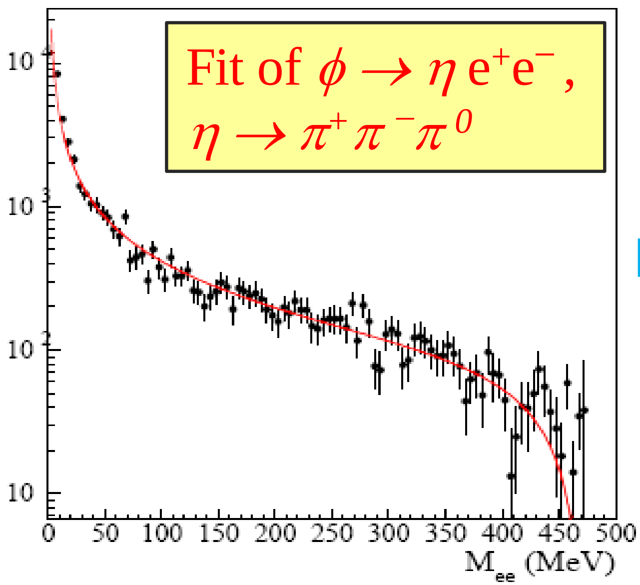
- $\phi \to \eta U$, $U \to e^+e^-$
- $e^+e^- \to Uh'$ (h' Higgs' strahlung) :
  - ($m_{h'} < m_U$) : $U \to l^+l^-$, h' – undetected ; process can be defined only by two detected leptons + missing mass
  - ($m_{h'} > m_U$) $h' \to UU \to 4l$ (multi – lepton events)

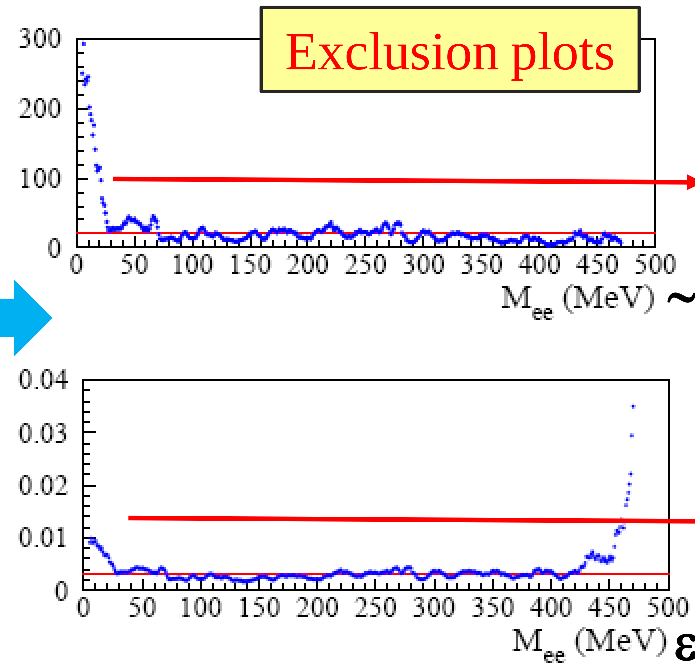
Search of the U–boson in $\phi \to \eta U$

- KLOE search $\phi \to \eta U$, $U \to e^+e^-$
  - $\eta \to \pi^+\pi^-\pi^0$ (preliminary result available), $\eta \to \gamma\gamma$ (in progress)
- Main irreducible background from $\phi \to \eta e^+e^-$ (BR measured in CMD–2, SND)
- KLOE obtained result (systematics not included) on 739 pb^{-1} ~ 20 events and

$\varepsilon < 3\times10^{-3}$ in the region 25 < Mee < 425 MeV

- KLOE–2 data taking can improve result to 10^{-3}



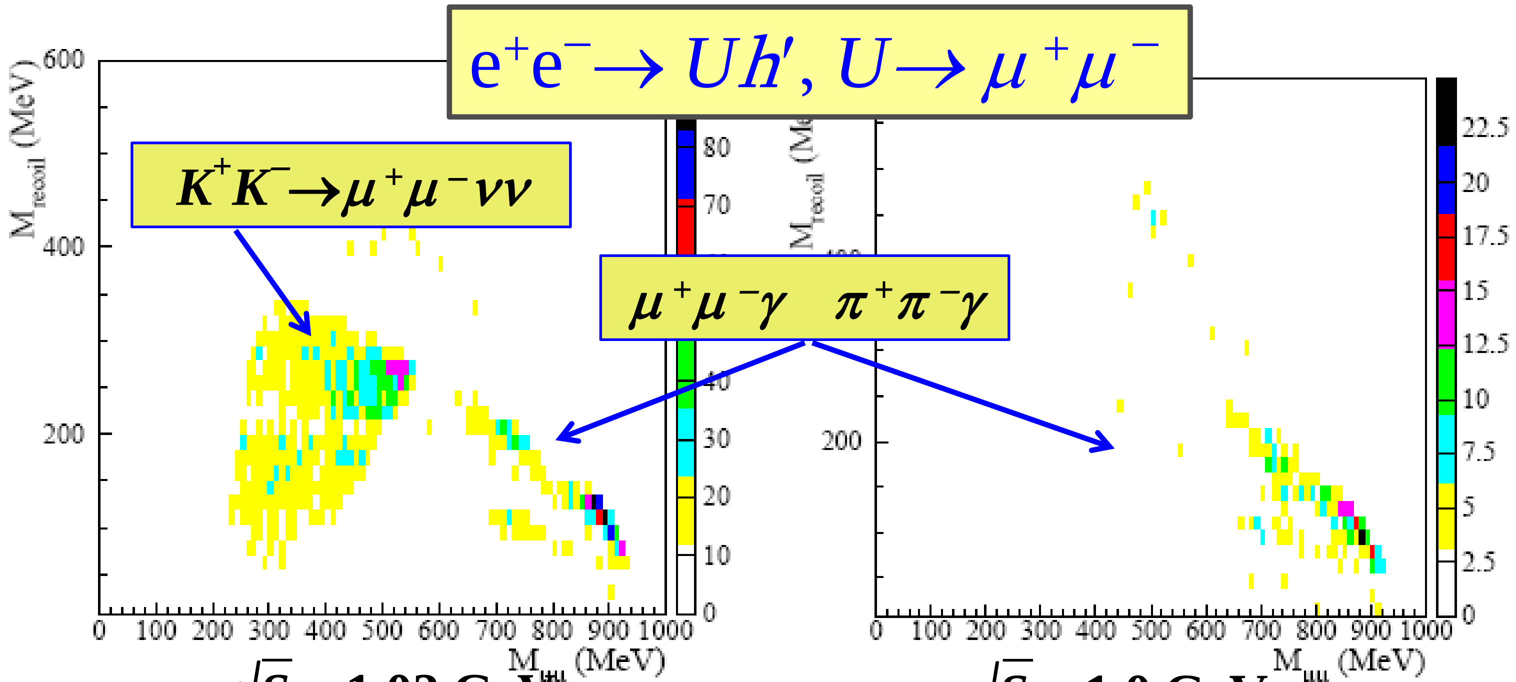


~ 20 events

ε~ 3×10^{-3}

Search of the U–boson in $e^+e^- \to Uh'$

- KLOE–data ($Lint.$ = 1.65 fb^{-1} $at\ \phi$ – peak and $Lint.$ = 0.2 fb^{-1} $\sqrt{S}$ = 1 GeV)
- Crucial background from $\phi \to K^+K^- / \pi^+\pi^-\pi^0$
- Possible decision to suppress background : using off–peak sample
- Next step: improvement of the vertex reconstruction (IT installation)



$\sqrt{S}$ = 1.02 GeV $\sqrt{S}$ = 1.0 GeV

Conclusions

✓New DAΦNE interaction scheme (crab-waist) is successfully implemented. It increased the old luminosity by factor 3 (instantaneous luminosity $\sim 4\times 10^{32}\ cm^{-2}\ s^{-1}$)

✓ DAΦNE is in commissioning phase

✓ KLOE–2 collaboration proposed a wide physics program

✓KLOE–2 is ready to start a long period of data-taking

✓ Installation of the taggers (HET and LET) gives a way to search $\gamma\gamma$ – physics processes

✓New detector upgrades (calorimeters and inner tracker) are planned to install next year

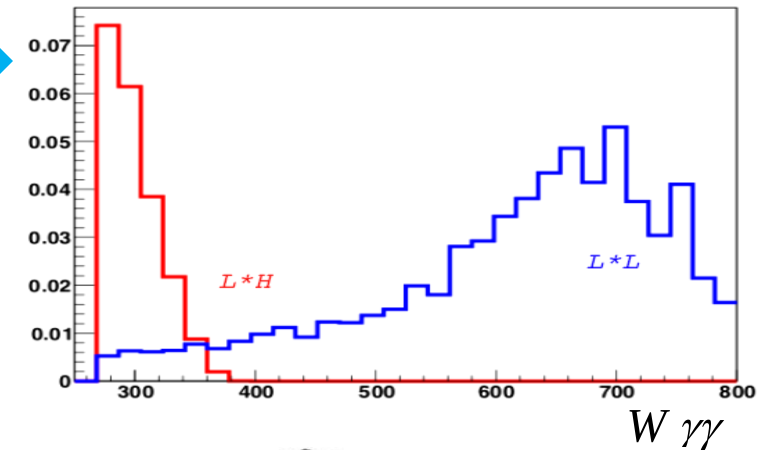
Thank You

SPARES

Tagging strategy for $\gamma\gamma$ – physics

- Studied $\gamma^* \gamma^* \to \pi^0 \pi^0$ (BDSIM/GEANT4)
- Single acceptance (only 1 tagger) = 54%
- Single arm acceptance :

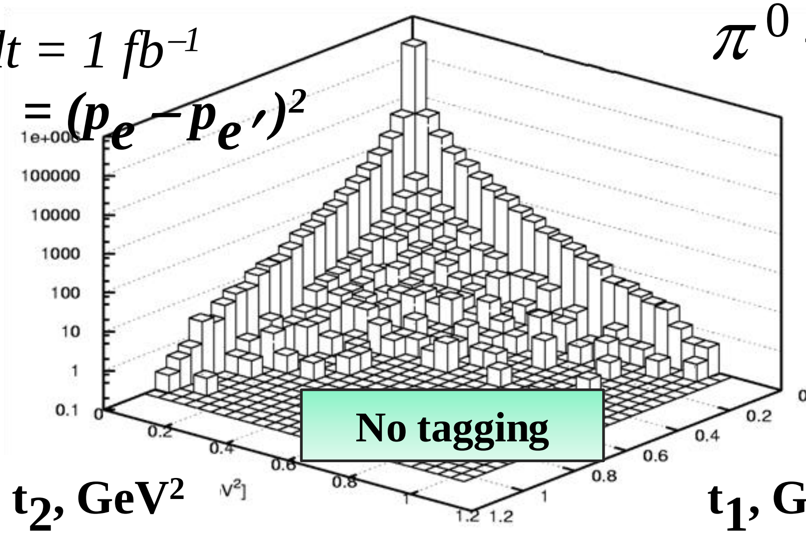
  HET = 14%, LET = 17%

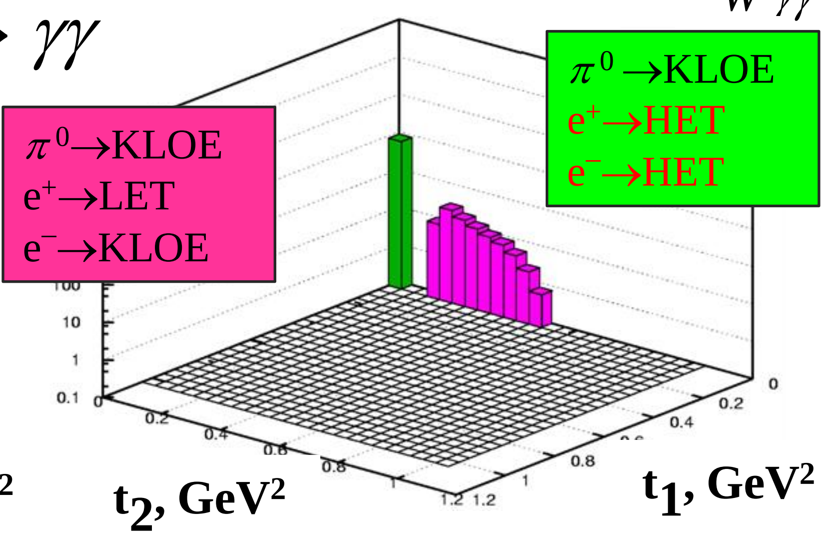


$\int Ldt = 1\ fb^{-1}$

$t_i = (p_e - p_e{}')^2$

$\pi^0 \to \gamma\gamma$





- HET × HET is enough for measurement of $\Gamma(\pi^0 \to \gamma\gamma)$ (EKHARA Monte Carlo generator)
- HET × HET + LET × KLOE is trigger for the form factors of $\gamma\gamma \to \pi^0, \eta$